Justifications for a Common Signaling Mode (CSM)

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Pulse~LINK is an industry leader in Ultra-Wideband (UWB) communications technologies. Formed in 2000, Pulse~LINK has over 130 issued patents and pending applications throughout the world. Pulse~LINK is currently developing UWB communications technologies for wireless and wired media applications. Pulse~LINK is pursuing the convergence of these on a single platform as a Software Defined Cognitive Radio solution. Pulse~LINK is also an early pioneer and proponent of a Common Signaling Mode for UWB and potentially all communications. This paper is directed toward the Common Signaling Mode for wireless communications. To date Pulse~LINK is the only company to announce UWB communications on wired media. To obtain information regarding this or other UWB communications technologies please contact Pulse~LINK at the above address.

The world of communications is a dynamic and rapidly changing arena in which technology is constantly evolving. The advent of wireless communication services is just one example of that rapid and dynamic change. Historically there have been a number of difficulties encountered in the wireless communications field. The "Spark Gap" invented in the 1890's by Marconi was capable of broadcasting around the globe. Unfortunately for Marconi, by the 1920's the airwaves were beginning to get crowded and "Spark Gap" transmitters did not coexist well with the new frequency based transmitters. As more frequency based transmitters began broadcasting audio the older spark gap transmitters were displaced. Eventually within the United States, the newly formed Federal Communications Commission (FCC) prohibited the use Spark Gap transmitters due to the potential interference issues associated with them.

Worldwide, spectrum is generally apportioned into licensed and unlicensed bands. The concept of an exclusive license is driven by the potential for harmful interference. "Mutual exclusivity is important because it is the statutory trigger as to whether the Commission is required to auction the spectrum."(1) Coexistence is therefore at the very core of Spectrum Management Policy both within the United States and without.

Within the US, the seeds of unlicensed spectrum usage have their root in the 1938 FCC decisions to authorize radio devices to transmit on a sufferance basis (2). Since that time, the FCC has continued to expand the spectrum allocations for unlicensed devices, recently opening up an additional 255 MHz of spectrum bandwidth in the 5.470-5.725 GHz band (3). The spectrum was made available for use by Unlicensed National Information Infrastructure (U-NII) devices, which include Radio Local Area Networks (RLANs), operating under Part 15 of the FCC's rules. This move is an example of an attempt to foster the development of new technologies and new capabilities that will serve the public interest. Similar examples exist on a basis as worldwide regulatory bodies attempt to accomplish the same goal of enabling innovation through the use of unlicensed spectrum.

Use of unlicensed spectrum, while sounding relatively simple and benign, is becoming more complex as the number of wireless technologies and users continues to grow. "The unlicensed bands do not provide for any real interference protection or for any exclusive licensee rights to spectrum. Instead, guided by some technical limitations, the bands are open to all comers so long as they operate approved equipment. This openness eliminates the entry barrier created by the auction price in the property-like rights model, but creates a different kind of barrier by imposing the more detailed technical rules of the common. In unlicensed bands, users rely on technology to overcome the risk of the traditional tragedy of the commons by engineering their devices so as to avoid any harmful interference."(1) As more and more devices and technologies are developed to take advantage of the unlicensed spectrum, the need for coexistence between systems only increases.

One prime historical example of this type of coexistence conflict is the battle between IEEE 802.11 LAN and Bluetooth, two wireless technologies designed to operate in the unlicensed bands at 2.4 GHz. IEEE 802.11 is a wireless LAN standard that is designed to support data rates of up to 54 Mbps. The 802.11 standards include a number of competing technologies in the same frequency band. Bluetooth is a short-range wireless technology designed for personal area networks. Bluetooth operates in the same 2.4 GHz unlicensed band. Since its inception, concerns have been raised over the potential conflicts between Bluetooth and 802.11 LAN technologies. In the US, these concerns have led to consumer hesitation with regards to the Bluetooth technology. For example, Navin Sabharwal states "Bluetooth adoption may be curtailed as network administrators are focused first and foremost on supporting 802.11b."(4) Additionally, fears that Bluetooth technologies might impact existing 802.11 wireless LANs brought an outright denial of the technology from some. "When the first Bluetooth products arrived on the market late last year, many corporate IS managers feared that Bluetooth devices might bring their 802.11b networks to their knees, and some corporate IS directors have issued an outright ban on Bluetooth devices, at least until the interference issues are worked out."(5) In another example, "Dave Rupp is trying to avoid what he calls "chaos-net." As the worldwide manager of local area network (LAN) services for Texas Instruments (TI), he's concerned about the coexistence of wireless RF systems. Specifically, he wants to avoid interference conflicts among devices trying to simultaneously access a Bluetooth personal area network (PAN) and a wireless Ethernet LAN (802.11b)."(6)

The concern about coexistence is not unique to these two technologies, but is actually a subset of the broader concern over spectrum coexistence for technologies utilizing the unlicensed portions of the spectrum. For example, the FCC's ET Docket No. 99-231 was initiated over concerns that a new wireless technology known as HomeRF would interfere with Bluetooth. HomeRF is another wireless networking protocol that is designed to support wireless LANs and voice communications. Docket No. 99-231 was the FCC's response to requests to resolve the potential interference issues between these two technologies by changing the Part 15 rules.

Coexistence issues for wireless communications devices will continue to compound as new devices come to market. "In the near future, it will be commonplace for cell phones to incorporate a variety of interfaces to Bluetooth, UWB, 802.11, GPS, and even TV."(7) This and other types of Advanced Telecommunications devices will have multiple coexistence issues. These issues alone drive the need for some method by which spectrum can be dynamically allocated and shared between disparate wireless technologies or devices. One possible solution to those issues is the concept of a Common Signaling Mode (CSM) by which disparate devices could dynamically allocate bandwidth usage between themselves.

A CSM can provide the mechanism for dynamic link adaptation and regulation of licensed and unlicensed device operation. "The success of the unlicensed approach depends in large part on the Commission's willingness and ability to clearly define the rules that govern the service. This is important if capital, and in turn, services, are to flow to the American people. The threat of the tragedy of the commons is real. And the Commission must recognize that risk and respond accordingly if it is to protect the vital contribution of unlicensed services."(1) If licensed and unlicensed devices implement a CSM, it will allow for significant benefits to all, and would reflect the goals and mission of worldwide regulatory bodies.

A Common Signaling Mode for All Wireless Communications Devices

Albert Einstein once said, "we cannot solve our problems with the same thinking we used when we created them."

The Common Signaling Mode (CSM) is a means by which disparate wireless technologies and devices may communicate with each other over a wireless interface. Ideally, it is a "Lowest Common Denominator" wireless mode understandable to all air interfaces. It is a methodology for allowing multiple different Physical layers (PHY) and technologies to coexist in the same spectrum bands and the same physical coverage areas simultaneously while maximizing the scalability and utilization of available spectrum. The CSM could function as a communications channel for cooperative management of allocated PHY resources across the time and frequency domains. In addition the CSM being a highly reliable, robust low-data rate signaling channel, the CSM could offer a wide variety of additional functional capabilities.

Such as:

- A Beacon Timing Channel.
- A Beacon Ranging Channel.
- A Low-data rate communications link for low-bandwidth devices.
- A power conservation functionality for mobile devices.
- A dynamic node-to-node power transmit / receive power control.
- Network status / health / control information.
- A low data rate Over-the-Air-Reprogramming link.
- A low data rate Over-the-Air-Rekeying for Security.
- CSM could be utilized for through-wall imaging systems.
- CSM could be used to support the FCC's Cognitive Radio Initiative.
- It could be used to support the FCC's Interference Temperature Initiative.
- It could be utilized for area security systems.

- The CSM could also enable a "Shut Down" Protocol.
- The CSM could serve as the PHY layer for IEEE 802.15.4a.
- The CSM could be used in a Mesh Network for routing updates.

A primary use of the CSM would be to provide a method for timing synchronization and bandwidth coordination between different wireless technologies utilizing dissimilar Physical layers For example, the use of a CSM could permit two devices, one a wireless device utilizing a spread spectrum approach to Ultra-Wideband (UWB) and the other using an Multi-Band Orthogonal Frequency Division Multiplexing (MB-OFDM) approach to Ultra-Wideband, to negotiate usage of the local spectrum based on a time sharing between the two devices. Alternatively the two devices may be a Bluetooth device and an 802.11 device attempting to operate within the same 2.4 GHz spectrum.

The CSM, if properly designed, has the potential to provide a CSM user a number of capabilities and services.

<u>a. CSM could provide Beacon Timing Channel</u>

By functioning as an out-of-channel communications mode that all wireless systems are capable of using, the CSM could provide for time synchronization across wireless networks by functioning as a wireless beacon. The concept of beacon signals is not new, they have been used in several different applications. For example, IS-95 uses the concept a Pilot Channel (8) in a manner similar to the concept of a beacon. In IS-95, the Pilot Channel is the beacon by which mobile units identify the base station. Part of the CSM packet structure could be designed to support the concepts of a timing beacon and the sharing of time information across wireless networks. By sharing time estimations between wireless devices, it becomes possible to generate highly precise time estimates across the network. Higher time accuracy across the network has the potential to provide for increased capacity, especially in Time Division Multiple Access (TDMA) networks by allowing higher time precision TDMA protocols to be utilized.

<u>b. CSM could provide Beacon Ranging Channel</u>

The CSM could permit an access point to function as a wireless positioning beacon. By allowing an access point to function as a beacon node, positioning applications would become more easily implemented. The concept of a beacon ranging channel is not a new one, it has been used in the Global Positioning System where each satellite acts as a beacon ranging channel. Two-way ranging creates possibilities for even more accurate ranging information. For example, multiple wireless beacon nodes transmitting continual position location information on their own location and estimates of ranges to other devices would enable a mobile device to rapidly determine its location. This would allow indoor E-911 applications to become more readily realizable.

<u>c. CSM could provide Low-Bandwidth communications link for low data rate devices</u>

The CSM could function as a low bandwidth communications channel. Low bandwidth messaging could utilize the CSM; thereby saving bandwidth for users that needed it. For example, a low data rate security sensor need not utilize a high-bandwidth communications link to report its status information, thereby saving that high data rate capacity for applications that needed it. It should be possible to design the CSM packet structure to readily support applications requiring low data rate communications.

d. CSM could provide power conservation functionality for mobile devices

By functioning as a low data rate communications channel, the CSM could enable power conservation in mobile or battery-limited devices. For example, devices requiring a low data rate channel would not need to continuously monitor a high-bandwidth channel to acquire or pass low data rate information. By utilizing the CSM, a mobile device is able to improve its power conservation, thereby ensuring longer operation.

e. CSM could provide dynamic node-to-node power transmit/receive power control

The CSM could be used by wireless links to dynamically control the power transmitted by each end of the link to ensure only the minimum transmit power needed to maintain the link was utilized by each end. This would be advantageous in applications such as mesh networking to ensure that the local RF environment was kept at the minimum level needed to maintain all the links. Additionally, the benefits of transmit power control through a CSM include the potential for a wireless device to take advantage of changing regulatory transmit power limits.[1]

f. CSM could provide network status/health/control information

The CSM could provide additional network functionality. Network status, health and control information could be readily provided over the low data rate, out-of-channel signaling mode the CSM would provide. For example, routing updates on node availability in a wireless mesh network could utilize the CSM instead of occupying a high data rate link.

g. CSM could provide a low data rate Over-the-Air-Reprogramming link

Functioning as a low data rate communications link, the CSM could enable on-the-fly software definable radios (SDR) in which the CSM link was used to pass new communications algorithms to the target receiver to enable new waveforms in near real-time. By being able to reprogram a radio over a low data rate communications channel wireless devices could be altered to modify and improve their transmission characteristics or to improve their capacity. As regulations change with respect to software definable radios and other cognitive radios, the CSM may be used to update software and firmware to conform to the new regulations. This Over-the-Air Reprogramming will allow devices to comply with a changing regulatory environment, thereby reducing the cost of redesign and replacement of wireless devices to designers, manufacturers, and consumers alike.

h. CSM could provide a low data rate Over-the-Air-Rekeying

Functioning as a low data rate communications link, the CSM could enable key distribution for secure networks thereby enabling over-the-air-rekeying of encryption devices. Security is a major concern in wireless architectures, as well as in communications in general. Encryption is one means of securing a communications link, be it wired or wireless. Secure encryption typically uses encryption keys that need to be changed on a dynamic basis. By creating a low data rate communications

[1] November 12, 2003 the US FCC adopted a Report and Order amending parts 2 and 15 of the Commissions rules regarding U-NII devices in the 5 GHz range. This Report and Order specifically required Transmit Power Control to be implemented in devices taking advantage of this frequency allocation.

channel, the CSM could enable the wireless rekeying of devices using encryption.

i. CSM could be utilized for through-wall imaging systems

CSM could be designed to enable through-wall and ground penetrating radar imaging systems by creating packets that had packet structures or synchronization headers that were fixed in nature and could be utilized as an imaging pulse train. For example, a packet training sequence could be designed to support through-wall imaging systems. Using the CSM, the through-wall imaging system need not transmit its own, special pulse sequence, thereby impacting the local radio frequency environment. Instead, perhaps the imaging device could utilize the CSM transmissions from other, near-by devices to complete its through-wall imaging.

j. CSM could be used to support the concept of Cognitive Radios

The IEEE has defined the Cognitive Radio as "a radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into (and out of, as necessary) the temporarily unused spectrum very rapidly, without interfering with the transmissions of other authorized users."(9) The FCC has defined Cognitive Radio technologies as those that "make possible more intensive and efficient spectrum use by licensees within their own networks, and by spectrum users sharing spectrum access on a negotiated or an opportunistic basis. These technologies include, among other things, the ability of devices to determine their location, sense spectrum use by neighboring devices, change frequency, adjust output power, and even alter transmission parameters and characteristics."(10) The FCC believes that cognitive radio technologies have the "potential to overcome some of the incompatibilities that exist between various communication services both domestically and worldwide."(10) The CSM could provide a cognitive radio the means by which spectrum negotiations could take place between dissimilar transmitters.

k. CSM could be used to support the concept of Interference Temperature

Another FCC initiative is the concept of Interference Temperature. The FCC's ET Docket No. 03-237 is a request for comments on the concept of a new model for quantifying and managing interference, called Interference Temperature. The FCC hopes this new concept could shift the current method for assessing interference, which is based on transmitter operations, to an approach that is based on the actual RF environment seen by a receiver while simultaneously taking into account the interactions between transmitters and receivers. The interference temperature model represents a fundamental paradigm shift in the FCC's approach to spectrum management by specifying a potentially more accurate measure of interference that takes into account the cumulative effects of all undesired RF energy, from both transmitters and potential noise sources, that is present at a receiver at any instant of time. Utilizing this new measure, the interference temperature limit for the band would serve as an upper bound on the potential RF energy that could be introduced into the band. By changing the current paradigm, the FCC hopes to increase the efficient use of spectrum and ensure coexistence of different wireless systems and technologies. A CSM would support the FCC's concept by creating a signaling channel that could be used by transceivers to communicate information on the local interference temperature. This would allow transceivers to dynamically adjust transmit power based upon the target receiver, thereby ensuring the local interference temperature limit was not exceeded.

l. CSM could be utilized for area security systems

Utilized in an Ultra-Wideband device, the CSM could be designed to enable area security systems, which would utilize the CSM as a radar-like detection signal. By appropriately designing the CSM, it may be possible to develop a packet sequence that could be used to detect motion within the area of the local device. It may be possible for a device to utilize the CSM transmissions from other devices as a detection signal. Such a capability would allow an Ultra-Wideband wireless device to become its own security sensor.

m. The CSM could also enable a "Shut Down" Protocol

Wireless devices are not readily accepted in all locations for reasons that vary from security concerns to social reasons. For example, wireless devices are not yet approved for use on airplanes for safety of flight reasons; they are not approved in hospitals for safety of life reasons; and they are typically not desired in movie theaters for social reasons. The CSM could be designed to turn off CSM enabled wireless devices when a CSM device entered such an area.

n. The CSM could serve as the PHY layer for IEEE 802.15.4a

The CSM could function as the IEEE 802.15.4a, Alternate Physical Layer Extension for Low Rate Wireless Personal Area Networks (WPAN), by providing communications and high precision ranging and location capability (with the goal being 1-meter accuracy or better), higher aggregate throughput, and significantly lower power. The 802.15.4a working group has been tasked with defining just such a standard and the concept of a CSM fits right into the existing definition.

o. The CSM could be used in a Mesh Network for routing updates

One problem in mobile mesh networks is the updating of routing information to nodes that are already saturated with traffic. By functioning as a separate, out-of-channel signaling mode, the CSM could provide updated routing information to saturated nodes, thereby permitting them to off-load traffic to different nodes. Additionally, traffic bandwidth would not be used up by common routing information, which would be sent by the CSM instead of occupying a traffic channel.

A Requirement for a Common Signaling Mode in All Wireless Communications Devices Furthers a Number of Worldwide Spectrum Policy Management Goals

Besides supporting the Interference Temperature and Cognitive Radio initiatives as discussed above, a CSM furthers a number of spectrum management objectives. By requiring a CSM for wireless communications devices, the wireless community would be encouraging the highest and best use of spectrum domestically and internationally in order to encourage the growth and rapid deployment of innovative and efficient communications technologies and services, as required by 47 CFR 301 and 303(g). For example, a CSM furthers all general objectives for spectrum defined in the FCC Strategic Plan FY 2003-2008.

a. Advance Spectrum Reform by Developing and Implementing Market-

Oriented Allocation and Assignment Reform Policies.

Flexibility of use promotes a market-oriented allocation system. "In a market allocation of spectrum, markets, not central authorities, determine spectrum uses and users. An ideal market allocation should impose no restrictions on spectrum uses and users beyond those necessary to limit interference, to prevent anti-competitive concentration, and to comply with international agreements. Spectrum should not be set aside for federal users or for specific non-federal users such as public safety providers, and public users should be allowed both to sell spectrum and buy spectrum from the private sector. For example, police and fire departments should be able to sell some of their spectrum and use the proceeds to buy new spectrum-conserving radios that could provide greater capacity and interoperability."(11)

An environment wherein a communications device may negotiate a license with a network to use spectrum would require a standard protocol for negotiation of a license. This standard protocol should be common to all wireless devices. A CSM is the logical solution to further this objective.

b. Vigorously Protect Against Harmful Interference and Enforce Public Safety-Related Rules.

As described above, a CSM enabled device may communicate important parameters to other devices. For example, a fixed access point may communicate to each mobile device the location of fixed transceivers and their known transmit powers and potentially their receiver sensitivity. A mobile device within the geographical coverage area of the known fixed transceiver may adjust its power level to prevent interference to the fixed service. Additionally, once a device calculates a local interference temperature it may communicate this information to other devices across a CSM as described above. When operating under a negotiated license within a public safety related frequency band, a CSM would allow the network to send a shutdown command to the device if the network needs to reclaim the spectrum for emergency use.

c. Conduct Effective and Timely Licensing Activities that Encourage Efficient Use of the Spectrum.

Automated licensing in the secondary market will require a standard interaction between a network and a device wishing access to the spectrum. A CSM can provide the protocols for this automated interaction.

d. Provide Adequate Spectrum and Improve Interoperability for Better Public Safety and Commercial Purposes.

A CSM would improve interoperability between all wireless communications devices. Additionally, it provides for automated bandwidth allocation between services. With the addition of interference temperature calculation by the devices and a CSM, public safety and commercial pursuits are better served because the potential for harmful interference to public safety wireless services is mitigated.

Ensuring Guaranteed Throughput

Many competing wireless technologies exist today. They range from cellular telephone systems, to wireless networking systems, to wireless devices used for simple control applications such as a garage door opener. Some of these technologies operate in spectrum that was granted to the technology owner through the granting of a spectrum license, while other technologies operate in spectrum that has been "opened" to all through regulations such as the FCC Part 15 Guidelines for use of "unlicensed" spectrum. Devices and technologies designed to operate in unlicensed spectrum must compete with each other for the use of that spectrum on an interference free basis (12).

Wireless networks are limited in their capacity by Shannon's Law (13), which states the capacity of a communications channel, C, is related to the average signal Power S, the average interfering noise power N, and the bandwidth W as follows:

$$C \leq W \log_2\left(1 + \frac{S}{N}\right)$$

Shannon's Law imposes a limit on the amount of information any communications channel may pass, and as such, is the absolute best any technology could hope to achieve in information flow. One key point regarding Shannon's Law is that it addresses a single communications channel in which one sender is attempting to pass data to one receiver over a single channel. Networking technologies, be they wired or wireless, are bound by Shannon's Law, but in turn are bounded by the fact that multiple users are attempting to communicate over what is essentially the same channel. This fact places additional burdens upon the communications capacity of a wireless channel. Given the fact that multiple users may at any time need to access the channel, Medium Access Control (MAC) techniques have been developed to ensure that users have equal access to the wireless communications channel. These MAC techniques range from techniques that divide channel access into specific time slots for users such as Time Division Multiple Access (TDMA) techniques, to techniques such as Code Division Multiple Access (CDMA) techniques, which separates user's access to the channel through the application of orthogonal codes. These techniques, as well as the many others that exist, have been created in order to "parse" out the communications channel to all users in as an efficient manner as possible and to permit each user full access to the communications channel.

These MAC techniques are intended to increase the throughput of each wireless user as efficiently as possible by coordinating access to the channel. Because there are typically multiple users attempting to access a wireless channel, a wireless network typically has less total throughput capability than a single communications channel would have. For example, under a Protocol Model of interference for an ad-hoc network, it has been shown that the maximum per-node throughput would be no more than $\frac{C'}{\sqrt{n \log n}}$ bits per second (14). Capacity limitations exist for all wireless networks and are based upon the number of users attempting to access the wireless channel. Given this fact, the best way to maximize this capacity for wireless networks is to ensure cooperation between wireless nodes/users (15). A CSM would provide the means by which users could cooperate in their access of the channel without the need for contention.

Through a common method of negotiation, i.e. a CSM, different wireless technologies or devices could effectively parse out spectrum utilization prior to the act of transmission, thereby attempting to mitigate the impacts of contention within the wireless media. By cooperatively negotiating the use of spectrum, disparate devices would be able to ensure access to spectrum as needed for throughput requirements or guaranteeing quality of service to specific users.

Design Goals for a Wireless CSM

A CSM for all wireless communications devices has the potential to offer a wide range of capabilities to users and to simplify the modernization of spectrum management. Ideally a CSM should incorporate today's technological capabilities, and also be scalable to include other future services and capabilities. At a minimum, the design goals for a **CSM should include:**

- A timing beacon.
- Information on coarse SYNCH, diversity, frequency acquisition, AGC, channel estimation, and protocol selection.
- A mechanism for a low power sleep mode.
- It should enable geo-positioning.
- It should provide for transmit power control.
- It should function as a low data rate link when channel conditions won't permit a high data rate link.
- It should address coexistence and interoperability among wireless devices.
- It should be low cost to implement.
- The CSM could be implemented as either a mandated RF channel across all wireless communications devices or as an abstraction layer protocol within each technology.

Conclusion

The world of wireless communication only continues to grow and expand, with new technologies continually being developed. Thus, the usage of spectrum will only continue to grow as wireless technologies continue to be developed. A Common Signaling Mode (CSM) is a potential method by which disparate wireless technologies could communicate with one another to negotiate the use of spectrum on an interference-free basis. The CSM could be a critical factor in enabling technologies such as cognitive radios and viral communications systems by functioning as a signaling protocol between different wireless communications technologies and systems. By functioning as a "least common denominator" communications link between all wireless systems, a CSM could bring about the full capabilities of technologies such as cognitive radio and viral communications systems and allow a harmonious use of spectrum between different and competing wireless technologies.

Regulatory bodies such as the FCC should require Advanced Telecommunications wireless devices to implement a CSM. By adopting this requirement, regulatory bodies will guarantee everyone access to both licensed and unlicensed wireless spectrum. Additionally, by requiring a CSM in wireless communications devices, new devices currently under development can be brought to market without concerns of coexistence and harmful interference. Finally, use of a CSM allows secondary markets for spectrum to be implemented in a standardized manner allowing more efficient use of this precious worldwide resource.

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